

1 CLAIMS:

2 Having thus described our invention, what we claim as
3 new and desire to secure by Letters Patent is as
4 follows:

5 1. A method for restoring a geometrically distorted
6 copy of a reference image, said method comprising:

7 automatically determining a type and amount of
8 distortion of said distorted copy; and

9 substantially reversing the distortion to form a
10 reoriented image.

11 2. A method as recited in claim 1, further comprising
12 horizontally and vertically aligning the reoriented
13 image with the reference image to form a realigned
14 image.

15 3. A method as recited in claim 2, further comprising
16 extracting a watermark from the realigned image.

17 4. A method as recited in claim 1, wherein the step of
18 automatically determining includes:

19 composing a geometric alteration of the distorted copy
20 by making the distorted copy the same size as the
21 reference image;

1 defining a safe area having safe pixels, wherein said
2 safe area is an intersection of pixels in the reference
3 image with pixels in the geometric alteration, and said
4 safe pixels includes any pixel from the reference image
5 or the geometric alteration which lies in the safe
6 area;

7 selecting 'n' points in the safe area, wherein 'n' is
8 at least three and not all 'n' points lie on a straight
9 line;

10 building a list of 'n' reference centers, wherein each
11 reference center corresponds to coordinates of a
12 particular pixel lying closest to a particular one of
13 said 'n' points;

14 constituting a plurality of pairs of sub-images,
15 wherein each pair is centered at one of said reference
16 centers and each pair is formed by a sub-image from the
17 geometric alteration and a corresponding sub-image from
18 the reference image;

19 minimally horizontally and vertically positioning from
20 an original sub-image position to a new sub-image
21 position any sub-image pair having any sub-image pixel
22 lying outside the safe area, such that said any
23 sub-image pixel lies within the safe area;

24 adjusting the reference center of said any sub-image
25 pair to correspond to said new sub-image position;

1 discarding said each distorted center and its
2 corresponding adjusted center that define a Euclidean
3 distance that is statistically improbable while
4 retaining at least three not-discarded distorted
5 centers and their corresponding adjusted centers; and

6 recomputing the coefficients matrix, A , of a pixel
7 position interpolation equation using the at least
8 three not-discarded distorted centers and corresponding
9 adjusted centers.

10 6. A method as recited in claim 4, wherein the steps
11 of substantially reversing includes:

12 factoring the sub-matrix S_A into four primitive image
13 manipulation matrices;

14 applying the four primitive image manipulation matrices
15 to the geometric alteration to produce a reoriented
16 image;

17 making the geometric alteration identical to the
18 reoriented image if any primitive image manipulation
19 matrix produces a distortion greater than a
20 predetermined threshold, said distortion determined by
21 examining all iteration-to-iteration incremental
22 changes in the Euclidean distances; and

23 repeating all the steps of claim 4 except the step of
24 composing, all the steps of claim 5, and the steps of

1 factoring, applying and making until no primitive image
2 manipulation matrix produces a distortion greater than
3 the predetermined threshold.

4 7. A method, as recited in claim 4, wherein the step
5 of horizontally and vertically aligning includes
6 translating horizontally the reoriented image by the
7 value of the third coefficient of the matrix, A, and
8 translating vertically the reoriented image by the
9 value of the sixth coefficient of the matrix, A, to
10 form the realigned image.

11 8. A method as recited in claim 3, wherein the step of
12 composing includes:

13 shrinking or enlarging the distorted copy vertically by
14 pixel interpolation or extrapolation such that the
15 produced geometric alteration has a same height as the
16 reference image, and

17 shrinking or enlarging the produced geometric
18 alteration horizontally by pixel interpolation or
19 extrapolation to have the same width as the reference
20 image.

21 9. A method as recited in claim 4, wherein the
22 coordinate offsets are non-integers and the step of
23 locating includes using interpolation.

1 10. A method, as recited in claim 1, wherein the
2 reference image is an original unmarked image.

3 11. A method as recited in claim 4, wherein the step
4 of computing includes:

5 comparing a region in the geometric alteration
6 surrounding each of said reference centers with regions
7 in the reference image shifted in position by a
8 multiplicity of coordinate offsets;

9 ascertaining horizontal and vertical coordinate offsets
10 of each selected reference center as being the
11 horizontal and vertical offset at which the region in
12 the geometric alteration and the region on the
13 reference image most nearly match; and

14 calculating the distorted centers from the coordinate
15 offsets and the corresponding reference centers.

16 12. A method as recited in claim 11, wherein the step
17 of comparing includes:

18 using a modified cross correlation function in which
19 the Fourier transform of the cross correlation function
20 is computed, wherein magnitudes of the Fourier
21 transform coefficients are modified to make said
22 magnitudes uniform, and

1 using an inverse Fourier transform to compute the
2 modified correlation function.

3 13. A method as recited in claim 11, wherein the step
4 of comparing includes:

5 using a weighted cross correlation function in which
6 the Fourier transform of the cross correlation function
7 is computed, wherein a weighted sum of the ordinary and
8 modified Fourier transform coefficients is formed, and

9 using an inverse Fourier transform to compute the
10 weighted correlation function.

11 14. A method as recited in claim 8, wherein the step
12 of ascertaining includes:

13 composing a geometric alteration of the distorted copy
14 by making the distorted copy the same size as the
15 reference image;

16 defining a safe area having safe pixels, wherein said
17 safe area is an intersection of pixels in the reference
18 image with pixels in the geometric alteration, and said
19 safe pixels includes any pixel from the reference image
20 or the geometric alteration which lies in the safe
21 area;

22 building a list of reference centers, wherein each
23 reference center corresponds to coordinates of a

1 particular pixel in the safe area lying closest to a
2 particular one of said at least three pixel locations;

3 computing a plurality of corresponding distorted
4 centers;

5 using the reference centers and the corresponding
6 distorted centers to compute coefficients of a matrix,
7 A, of pixel position interpolation equations;

8 testing each distorted center to determine if said each
9 distorted center is statistically improbable; and

10 discarding each distorted center that is statistically
11 improbable while retaining at least three not-discarded
12 distorted centers until no more distorted centers are
13 discarded.

14 15. An article of manufacture comprising a computer
15 usable medium having computer readable program code
16 means embodied therein for causing a restoring of a
17 geometrically distorted copy of a reference image, the
18 computer readable program code means in said article of
19 manufacture comprising computer readable program code
20 means for causing a computer to effect:

21 automatically determining a type and amount of
22 distortion of said distorted copy; and

1 substantially reversing the distortion to form a
2 reoriented image.

3 16. An article of manufacture as recited in claim 15,
4 the computer readable program code means in said
5 article of manufacture further comprising computer
6 readable program code means for causing a computer to
7 effect horizontally and vertically aligning the
8 reoriented image with the reference image to form a
9 realigned image.

10 17. An article of manufacture as recited in claim 16,
11 the computer readable program code means in said
12 article of manufacture further comprising computer
13 readable program code means for causing a computer to
14 effect extracting a watermark from the realigned image.

15 18. An article of manufacture as recited in claim 15,
16 wherein the reference image is a copy of an original
17 unmarked image.

18 19. An article of manufacture as recited in claim 15,
19 wherein the step of automatically determining includes:

20 selecting a set of at least three reference centers in
21 the geometric alteration;

22 comparing a region in the geometric alteration
23 surrounding each of said reference centers, with

1 regions in the reference image shifted in position by a
2 multiplicity of coordinate offsets;

3 ascertaining horizontal and vertical coordinate offsets
4 of each selected reference centers as being the
5 horizontal and vertical offset at which the region in
6 the geometric alteration and the region on the
7 reference image most nearly match; and

8 determining the type and amount of distortion from the
9 coordinate offsets and the set of reference centers.

10 20. An article of manufacture as recited in claim 19,
11 wherein the step of comparing includes:

12 using a modified correlation function in which the
13 Fourier transform of the correlation function is
14 computed, wherein the magnitudes of the Fourier
15 transform coefficients are modified to make said
16 magnitudes uniform, and

17 using an inverse Fourier transform to compute the
18 modified correlation function.

19 21. An article of manufacture as recited in claim 19,
20 wherein the step of ascertaining includes performing a
21 least-squares fit on the horizontal and vertical
22 coordinate offsets of the set of reference centers.

22. A computer program product comprising a computer usable medium having computer readable program code means embodied therein for causing a readjusting of a geometrically distorted copy of a reference image, the computer readable program code means in said computer program product comprising computer readable program code means for causing a computer to effect:

automatically determining a type and amount of distortion of said distorted copy; and

substantially reversing the distortion to form a reoriented image.

23. An apparatus for restoring a geometrically distorted copy of a reference image, said method comprising:

means for automatically determining a type and amount of distortion of said distorted copy; and

means for substantially reversing the distortion to form a reoriented image.

24. An apparatus as recited in claim 23, further comprising horizontally and vertically aligning the reoriented image with the reference image to form a realigned image.

1 25. An apparatus as recited in claim 24, further
2 comprising means for extracting a watermark from the
3 realigned image.

4 26. An apparatus as recited in claim 23, wherein the
5 means for automatically determining includes:

6 means for composing a geometric alteration of the
7 distorted copy by making the distorted copy the same
8 size as the reference image;

9 means for defining a safe area having safe pixels,
10 wherein said safe area is an intersection of pixels in
11 the reference image with pixels in the geometric
12 alteration, and said safe pixels includes any pixel
13 from the reference image or the geometric alteration
14 which lies in the safe area;

15 means for selecting 'n' points in the safe area,
16 wherein 'n' is at least three and not all 'n' points
17 lie on a straight line;

18 means for building a list of 'n' reference centers,
19 wherein each reference center corresponds to
20 coordinates of a particular pixel lying closest to a
21 particular one of said 'n' points;

22 means for constituting a plurality of pairs of
23 sub-images, wherein each pair is centered at one of
24 said reference centers and each pair is formed by a

- 1 sub-image from the geometric alteration and a
- 2 corresponding sub-image from the reference image;
- 3 means for minimally horizontally and vertically
- 4 positioning from an original sub-image position to a
- 5 new sub-image position any sub-image pair having any
- 6 sub-image pixel lying outside the safe area, such that
- 7 said any sub-image pixel lies within the safe area;
- 8 means for adjusting the reference center of said any
- 9 sub-image pair to correspond to said new sub-image
- 10 position;
- 11 means for computing a two-dimensional cross correlation
- 12 surface from each of the 'n' pairs;
- 13 means for locating a horizontal, p_n , and a vertical,
- 14 q_n , coordinate offset of the greatest peak on each
- 15 cross-correlation surface;
- 16 means for calculating a plurality of distorted centers;
- 17 means for using the adjusted centers and the
- 18 corresponding distorted centers to compute the
- 19 coefficients matrix, A, of a pixel position
- 20 interpolation equation; and
- 21 means for forming a sub-matrix, S_A , from the first,
- 22 second, fourth and fifth elements of the matrix A.

1 27. An apparatus as recited in claim 26, further
2 comprising:

3 means for computing a set of proposed reference centers
4 based on the distorted reference centers and the pixel
5 position interpolation equations;

6 means for computing the Euclidean distances between the
7 proposed reference centers and the adjusted centers;

8 means for testing each Euclidean distances to determine
9 if said each Euclidean distance is statistically
10 improbable;

11 means for discarding said each distorted center and its
12 corresponding adjusted center that define a Euclidean
13 distance that is statistically improbable while
14 retaining at least three not-discarded distorted
15 centers and their corresponding adjusted centers; and

16 means for recomputing the coefficients matrix, **A**, of a
17 pixel position interpolation equation using the at
18 least three not-discarded distorted centers and
19 corresponding adjusted centers.

20 28. An apparatus as recited in claim 26, wherein the
21 coordinate offsets are non-integers, and the means for
22 locating includes using interpolation.

1 29. A method as recited in claim 1, wherein the steps
2 of automatically determining and substantially
3 reversing are repeatedly applied until an amount of the
4 distortion falls below a given threshold.

5 30. A method as recited in claim 29, wherein the given
6 threshold is less than a 0.5 pixel spacing.

7 31. A method comprising:

8 automatically measuring the degree of
9 distortion imparted upon a distorted replica
10 of an original image;

11 substantially reversing the degree of
12 distortion of the distorted replica to form
13 an undistorted image; and

14 aligning the undistorted image with the
15 original image.

16 32. A method as recited in claim 31, further
17 comprising determining whether the distorted replica
18 image has been geometrically distorted relative to
19 another form of the original image.

20 33. An article of manufacture comprising a computer
21 usable medium having computer readable program code
22 means embodied therein for causing restoration of an
23 image, the computer readable program code means in said

1 article of manufacture comprising computer readable
2 program code means for causing a computer to effect:

3 automatically measuring the degree of
4 distortion imparted upon a distorted replica
5 of an original image;

6 substantially reversing the degree of
7 distortion of the distorted replica to form
8 an undistorted image; and

9 aligning the undistorted image with the
10 original image.

11 34. An article of manufacture as recited in claim 32,
12 the computer readable program code means in said
13 article of manufacture further comprising computer
14 readable program code means for causing a computer to
15 effect determining whether the distorted replica image
16 has been geometrically distorted relative to another
17 form of the original image.

18 35. A method as recited in claim 4, wherein the step
19 of selecting 'n' points includes employing a simulated
20 mesh with knots.